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Greenhouse Evaluation of Reclamation Treatments for Perlite-Pumice Mine Spoils

**Bryan D. Williams
Ray W. Brown
Roy C. Sidle
Walter F. Mueggler**

THE AUTHORS

BRYAN D. WILLIAMS is the senior forestry technician on the Reclamation of Disturbed Lands research work unit with the Intermountain Research Station, Logan, UT.

RAY W. BROWN is principal plant physiologist on the Reclamation of Disturbed Lands research work unit at Logan. His main areas of research include plant/water relations and reclamation of disturbed lands.

ROY C. SIDLE is project leader and research hydrologist for the Reclamation of Disturbed Lands research work unit at Logan.

WALTER F. MUEGGLER, now retired, was principal plant ecologist for the Intermountain Research Station and now serves as a Forest Service volunteer.

RESEARCH SUMMARY

In greenhouse trials we studied the effects of three fertilizer levels and a surface straw mulch on the growth and development of two grass species, thickspike wheatgrass and Hycrest wheatgrass, grown in perlite ore, pumice ore, and perlite mill waste (a byproduct of pelite ore crushing and screening). These materials came from the National Perlite Products mine located in Oneida County in southeastern Idaho, and are representative of materials found in the area. The results show that fertilization is necessary for grass establishment and that increasing fertilizer rates result in significant ($p \leq 0.05$) increases in aboveground biomass (up to 45-fold), belowground biomass (up to twentyfold), number of culms (ninefold), and average leaf length (up to 80 percent) over no fertilizer levels. A surface mulch application equal to 2,200 kg/ha (2,000 lb/acre) produced a small but significant reduction in all the measured plant growth parameters. Due to low cation exchange capacity and low water-holding characteristics of these materials, incorporation of organic matter into the soil profile is recommended. The two grass species appear to be well suited for reclamation of these materials.

Intermountain Research Station
324 25th Street
Ogden, UT 84401

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INTRODUCTION

Surface mining presents resource managers with the challenging problem of establishing vegetation on large disturbances covered by mine spoils. These spoils usually have uncertain structure, low nutrient availability, and often phytotoxic compounds. This is especially true in the arid and semiarid West where limited rainfall during the growing season and high soil surface temperatures frequently limit plant establishment and growth. Considerable information has been accumulated over the past 15 years on techniques for revegetating spoils resulting from the surface mining of some of the more common commodities such as coal (Fisher 1983; Wali 1978), phosphates (Farmer and Blue 1978), copper, silver, and gold (Brown and Chambers 1989; Brown and others 1978; Johnston and others 1975) and drastically disturbed lands in general (Allen 1988; Schaller and Sutton 1978; Thames 1977; Wali 1975). Little is known, however, about the unique spoil properties that must be considered for establishment of vegetation on spoils of less common minerals such as perlite and pumice.

Recent expansion of open-pit mining activity for perlite and pumice in Oneida County of southeastern Idaho has raised questions regarding the feasibility of establishing stabilizing vegetation on the increasingly abundant spoil materials from such operations. Both perlite and pumice are a product of volcanism. Perlite is a glassy volcanic rock that has the unusual characteristic of expanding up to 20 times its original volume when appropriately heated. In its crude form it is essentially a metastable amorphous aluminum silicate that has a pH of approximately 7 and is chemically inert. In its expanded form it is used for a wide variety of products such as noncombustible insulation, soil conditioner, acoustical plaster, a filter to purify liquids, and as an inert carrier for pesticides. Pumice is essentially an aluminum silicate with a cellular structure formed by a process of explosive volcanism. Pumice also has a variety of commercial uses and is valued primarily as a lightweight concrete aggregate and as an abrasive for cleaning and scouring compounds (cover photo).

Of initial concern was the suitability of the spoil material for supporting vegetation growth. We conducted chemical analyses on three different spoil materials to determine nutrient limitations, followed by a greenhouse study during the winter of 1987-88. The primary objective was to determine the effects of standard reclamation techniques of fertilization and mulching on plant growth responses in perlite and pumice spoils. Additionally, we compared the performance of a native rhizomatous grass growing on the site and a drought-resistant introduced grass similar to that commonly used for range revegetation in the area.

METHODS

Three types of spoil material were examined: (1) pumice ore, (2) perlite ore, and (3) perlite mill waste consisting of impurities and undersized materials resulting from the crushing and screening of perlite ore. Preliminary soil analyses from duplicate grab-samples of each of the three spoil types provided the basis for determining nutrient additives to be tested in the greenhouse. The results of these analyses (table 1) indicated a general need for additions of nitrogen (N), phosphorus (P), potassium (K), and sulfur (S) to raise the fertility to a level suitable for the growth of grasses. We tested the growth potential of each of the three spoil types with three fertilization treatments: (1) a high rate consisting of 67 kg/ha (60 lb/acre) of N, 34 kg/ha (30 lb/acre) of P, 45 kg/ha (40 lb/acre) of K, 11 kg/ha (10 lb/acre) of iron (Fe) and 100 kg/ha (90 lb/acre) of S; (2) a low rate of one-half of the above rate for each nutrient; and (3) no fertilization. Nitrogen was added in the form of ammonium sulfate, P was applied as superphosphate, K was applied as potassium chloride, Fe was applied as iron sulfate, and the S application was calculated from the sulfur component of the other fertilizers. In addition, tests were run with and without surface mulching. Half the pots were mulched with straw at an equivalent rate of 2,200 kg/ha (2,000 lb/acre) to ameliorate the high soil surface temperatures and to reduce evaporation. Mulch would typically be applied in a field reclamation situation to prevent surface erosion and seed displacement. Thus, it was desirable to see how mulching would effect first year soil fertility and plant growth.

Two grass species of different growth forms were used in the greenhouse trial: (1) thickspike wheatgrass (*Agropyron dasystachyum* [Hook.]), a rhizomatous grass native to the area, and (2) Hycrest wheatgrass (*Agropyron cristatum* [L.] Gaertner X *Agropyron desertorum* [Fischer ex Link] Schultes), a recently developed tussocked hybrid

Table 1—Initial soil analyses for the three different spoil materials used in the growth tests

Element/characteristic	Perlite ore	Pumice ore	Perlite mill waste
Organic matter (percent)	[1]0.3	0.1	0.4
Soil pH	8.6	8.4	7.0
Bicarbonate P (mg/kg)	6	4.6	6.4
Potassium (mg/kg)	70	42	68
Magnesium (mg/kg)	87	34	66
Calcium (mg/kg)	1,090	893	558
Nitrate (mg/kg)	6	4	4
Sulfur (mg/kg)	13	4	5
Zinc (mg/kg)	27.9	1.2	1.4
Hydrogen (meq/100 g)	0.0	0.0	0.0
Cation exchange capacities (meq/100 g)	6.4	2.2	3.5
Percent base saturation:			
K (percent)	2.8	5.0	5.0
Mg (percent)	11.4	13.3	15.6
Ca (percent)	85.8	81.7	79.4
H (percent)	0.0	0.0	0.0
Soil separates:			
Sand (percent)	82	83	84
Silt (percent)	13	13	9
Clay (percent)	5	4	7

[1]Values are means; $n = 3$.

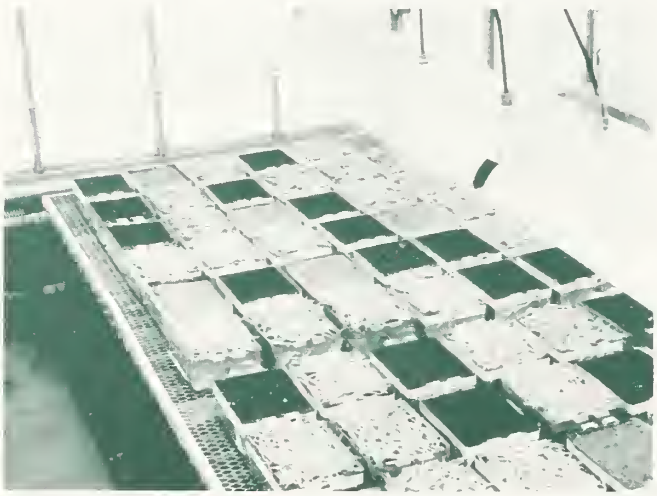

Figure 1—Greenhouse study design layout; dark-colored material is mill waste, light gray material is pumice or perlite. Straw mulch covers the surface on one-half of the pots.

with relatively good growth and drought-tolerance characteristics (Asay and Knowles 1985). Each species was planted in separate rectangular pots containing combinations of spoil type, fertilizer level, and presence or absence of mulch. The individual pots were of 19 by 27 cm (7.5 by 11 inches) surface dimension, and were filled to a depth of approximately 14 cm (5.5 inches). Several seeds were planted in six evenly spaced locations in each pot, and upon germination thinned to a single established individual at each of these six locations. There were three replications for each treatment.

The study design consisted of a randomized block test containing three blocks, three spoil materials, three fertilizer levels, two mulch conditions, and two species ($n = 108$) randomly distributed within each block (fig. 1). All test pots were maintained at a high level of available water adequate for plant growth.

At the end of a 110-day growth period, the following plant characteristics were measured: number of grass culms, culm length, aboveground biomass, and belowground biomass. In addition, chemical analyses were obtained for the spoil material in the pots (table 2) and of the aboveground plant tissue to obtain total nutrient uptake (AOAC 1984).

The data were analyzed by analysis of variance ($p \leq 0.05$) and mean comparisons with Fisher's protected least significant differences (Steel and Torrie 1980).

Table 2—Methods of soil analysis

Soil property	Method
pH	Glass electrode in a 1:1 slurry of soil and distilled water (McLean 1980)
OM (percent)	Chromic acid digestion with colormetric determination (Walkley and Black 1934, as modified by Schulte 1980)
NO_3 (mg/kg)	Specific ion electrode in a saturated calcium sulfate extraction (Carson 1980a)
P (mg/kg)	Extraction with 0.5M $NaHCO_3$ at pH of 8.5 (Olsen and others 1954)
K, Mg, Ca, Na (mg/kg)	Flame photometry of a 1 soil:5, 1N ammonium acetate extraction (Carson 1980b; Doll and Lucas 1973)
Na (mg/kg)	Flame photometery of a 1N ammonium acetate extraction (American Society of Agronomy 1982)
Zn (mg/kg)	DTPA extraction (Lindsay and Norvell 1978; Whitney 1980)
Texture (percent)	Hydrometer method of particle size analysis (Day 1973)

RESULTS

As expected, the amount of fertilization substantially and progressively increased the growth of both grasses. The unfertilized spoil material, regardless of origin, marginally supported plant growth, whereas the heavily fertilized spoils supported substantial growth (fig. 2). The differences among all three levels of fertilizer application were statistically significant for all plant growth characteristics measured: aboveground biomass production, belowground biomass production, number of grass culms, and culm length (table 3). Overall, the low level of fertilization produced approximately a 25-fold increase in aboveground production, a fifteenfold increase in belowground production, a sevenfold increase in number of grass culms, and 60 percent increase in the length of culms, compared to untreated spoils. The high level of fertilization produced approximately a 45-fold increase in aboveground production, a twentyfold increase in belowground production, a ninefold increase in number of culms, and about an 80 percent increase in culm length compared to untreated spoils. Doubling the amount of fertilizer from 33 to 66 kg/ha increased aboveground biomass by 69 percent, increased belowground biomass by 36 percent, increased the number of grass culms by 38 percent, and increased the length of culms by 11 percent.

Aboveground biomass production was least for grasses grown on the perlite ore compared to the other two substrates (table 3). Although the initial soil analyses (table 1) indicated that perlite ore had at least as good a fertility status as the other two substrates, soil analyses following completion of the experiment showed a depletion of nitrate (NO_3) in the perlite ore (table 4). Neither culm length nor number of culms differed significantly among the various spoil materials.

The mulch treatment had an opposite effect to that anticipated, in that mulching slightly inhibited plant growth in this greenhouse trial. Both above- and belowground biomass, as well as numbers of culms, were significantly lower in the mulched pots (table 3). Apparently the use of mulch for reducing plant water stress under the nonstressful greenhouse conditions was offset by the detrimental effect of surface heat trapping by the mulch (Cochran 1969), or possibly by creating a C:N imbalance.

The two wheatgrasses generally responded similarly on the different spoil materials and to the different amendments. Thickspike wheatgrass, however, produced slightly more culms and somewhat lower belowground biomass than Hycrest wheatgrass (table 3). These differences, although statistically significant, were not reflected by the other growth measurements.

A significant interaction occurred between the type of spoil material and the level of fertilization for aboveground biomass, belowground biomass, and number of culms (fig. 3). The perlite mill waste produced significantly more aboveground biomass with low fertilization than either the perlite or pumice ore, and both the perlite mill waste and pumice ore produced more biomass with high fertilization than did the perlite ore. At both low and

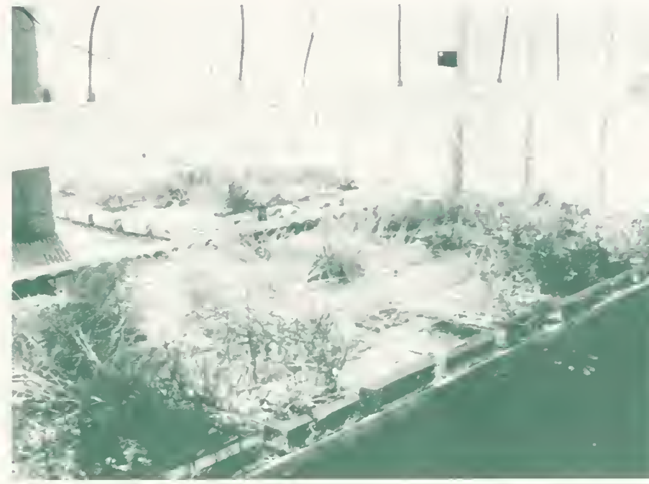

Figure 2—Grass development near the end of the assessment period; notice the nonfertilized pots located in the foreground near center of the bench.

Table 3—Significant effects ($p \leq 0.05$) of different spoil materials and different treatments on plant growth characteristics. Means in the same row followed by different letters differ significantly

Plant characteristic	Spoil material: Perlite	Pumice	Perlite mill waste
Aboveground production (g/pot)	5.66 A	7.36 B	7.71 B
Belowground production (g/pot)	9.08 A	11.26 B	8.56 A
	Fertilization: None	**Low**	**High**
Aboveground production (g/pot)	0.28 A	7.61 B	12.84 C
Belowground production (g/pot)	.77 A	11.94 B	16.19 C
Number of culms (No./pot)	14.5 A	96.4 B	133.0 C
Average culm length (mm)	114. A	184. B	204. C
		Mulch: Yes	**No**
Aboveground production (g/pot)		6.48 A	7.34 B
Belowground production (g/pot)		8.85 A	10.42 B
Number of culms (No./pot)		76.6 A	86.0 B
		Grass type: Thickspike wheatgrass	**Hycrest wheatgrass**
Belowground production (g/pot)		8.38 A	10.88 B
Number of culms (No./pot)		87.5 A	75.1 B

Table 4—Significant effects ($p \leq 0.05$) of different spoil materials and fertilizer levels on soil nutrient status following 110 days of plant growth. Means in the same row followed by different letters differ significantly

Soil characteristic	Perlite		Pumice		Perlite mill waste	
	No fertilization	High fertilization	No fertilization	High fertilization	No fertilization	High fertilization
Soil pH	8.7 A	8.3 A	8.7 A	7.5 B	8.2 A	6.7 C
Nitrate (mg/kg)	6.2 A	3.8 B	10.3 C	5.2 AB	8.3 C	5.3 AB
Bicarbonate P (mg/kg)	5.8 A	11.8 B	5.0 A	10.6 BC	5.8 A	9.6 C
Potassium (mg/kg)	80.8 A	69.6 B	52.2 C	45.4 C	72.0 B	61.5 D
Magnesium (mg/kg)	90.7 A	82.2 B	42.2 C	46.3 C	75.0 D	76.0 D
Calcium (mg/kg)	1,158.0 A	1,118.0 B	357.0 C	338.0 C	597.0 D	534.0 E
Sodium (mg/kg)	23.7 A	23.0 B	22.4 B	18.5 CD	21.2 BC	16.8 D
CEC (meq/100 g)	6.8 A	6.6 A	2.4 B	2.3 B	3.9 C	3.6 C

high fertilization levels, the pumice ore produced significantly more belowground biomass than either the perlite ore or perlite mill waste. No significant differences in belowground biomass production were noted for the unfertilized treatment. With no fertilization the perlite mill waste produced a significantly greater number of grass culms than either the perlite ore or the pumice ore. In the two fertilizer treatments, culm production among the substrate types was almost identical.

Plant nutrient uptake for the unfertilized and high fertilizer treatments paralleled biomass production. The 45-fold difference between the zero and high fertilizer levels for aboveground biomass production was reflected in an average 46-fold greater uptake of N, a 45-fold greater uptake of P, a 55-fold difference in K, and a thirtyfold difference in Ca (table 5). In general the two wheatgrasses did not differ significantly in the amount of nutrient uptake. Total elemental uptake was significantly higher in those plants growing in the fertilized versus nonfertilized pots. Generally, plant nutrient uptake was significantly lower from the perlite ore than from either the pumice ore or the perlite mill waste (table 6). This again paralleled the smaller amount of biomass production from the perlite ore versus the other two spoil materials. The exceptions were magnesium (Mg), calcium (Ca), aluminum (Al), and zinc (Zn), which did not differ significantly among the different spoil materials. Plant uptake of sodium (Na) was significantly higher from the perlite ore than from the other materials.

Soil nutrient analyses at the end of the 110-day plant growth period revealed differences in nutrient concentrations remaining in the different spoil materials with and without fertilization (table 4). With the exception of bicarbonate phosphorus, significantly more of all of the nutrients examined were extracted by the plants growing in the fertilized than in the nonfertilized spoils. A difference also was observed among soil types. Neither the presence of mulch nor the type of wheatgrass growing on the spoil material significantly affected the amount of remaining nutrients. High fertilization significantly reduced the pH level on both the pumice ore (from 8.7 to 7.5) and perlite mill waste (from 8.2 to 6.7), but not on the perlite ore. In most cases there was significantly less NO_3, K, Ca, and Na present in the fertilized than in the nonfertilized spoil materials. The lower amount of these elements in the fertilized spoils can be explained by differences in plant growth. The comparatively large amount of root growth in the fertilized spoils fully occupied the pots and permitted nutrient extraction from the entire pot volume. This was not true of the unfertilized pots, which had very limited root growth confined to the upper portion of the pots. As a consequence, this limited root distribution was unable to extract nutrients from the entire pot volume.

Interestingly, the data suggest that the amount of K, Mg, Ca, and NO_3 in the unfertilized spoils (table 4) was somewhat higher than these nutrient levels prior to the start of plant growth (table 1). Theoretically, the levels should be less. We were unable to test the statistical significance of the differences because of the limited sample of spoil nutrients before plant growth. The discrepancy is believed to result from the limited number and variability of pregrowth samples.

CONCLUSIONS AND RECOMMENDATIONS

Perlite ore, pumice ore, and perlite mill waste do not contain sufficient nutrients to support the establishment and growth of vegetation needed for adequate revegetation. Initial soil analyses indicated deficiencies of all macronutrients on all three substrates. Although we did not test for all micronutrients, tests for S and Zn were also low. A single application of 33 kg/ha (30 lb/acre) of N (as ammonium sulfate), 17 kg/ha (15 lb/acre) of P (as superphosphate), 22 kg/ha (20 lb/acre) of K (as potassium chloride), and 6 kg/ha (5 lb/acre) of Fe (as iron sulfate) will increase the nutrient level sufficiently to enable the establishment of vegetation cover. Doubling the amount of fertilizer will increase the amount of above- and belowground plant biomass substantially. If the intent, however, is to return areas to a native grass/shrub cover, the lower rate of fertilization may be the most appropriate (Chambers 1989). Because of the coarse texture of these spoil materials and their low cation exchange capacities,

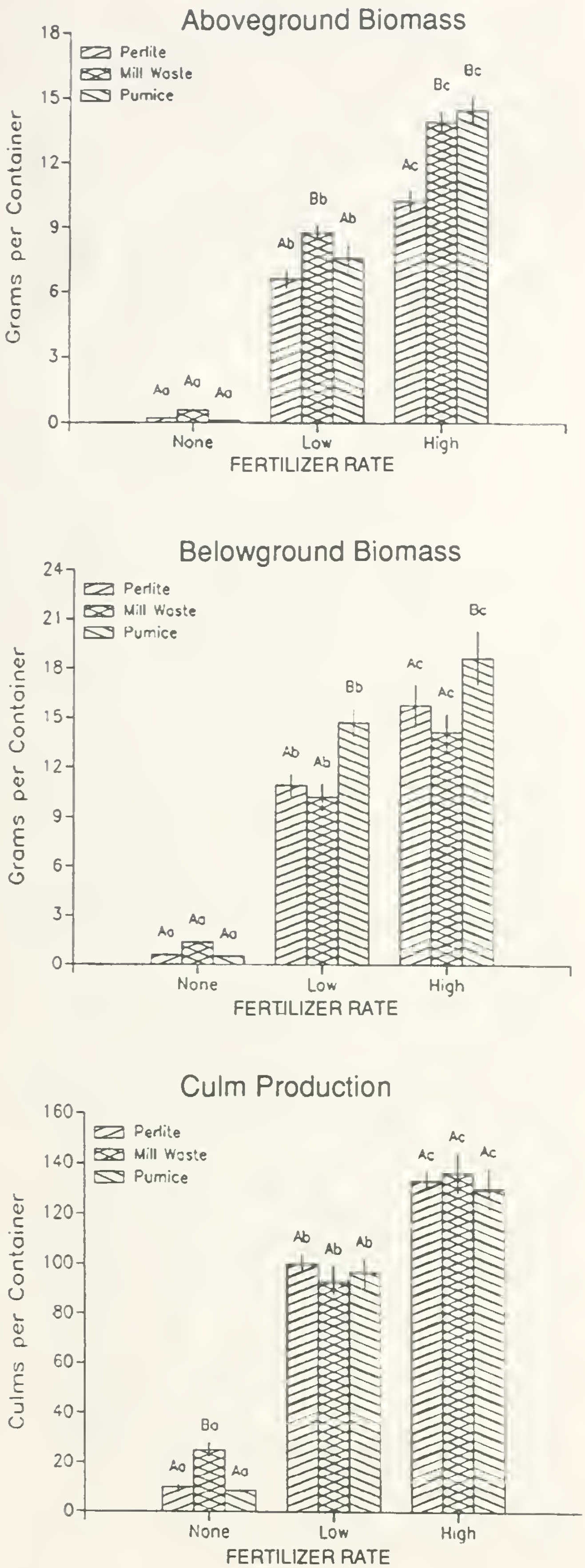

Table 5—Nutrient uptake (micrograms/pot) by aboveground plant tissue of thickspike and Hycrest wheatgrasses following 110 days of growth on the nonmulched pots, with two levels of fertilization. Means in the same row followed by different letters differ significantly ($p \leq 0.05$)

	No fertilization		High fertilization	
Element	**Thickspike**	**Hycrest**	**Thickspike**	**Hycrest**
Nitrogen	3.19 A	3.37 A	152.86 B	149.96 B
Phosphorus	.65 A	.61 A	28.62 B	27.76 B
Potassium	3.39 A	3.82 A	200.67 B	197.51 B
Sulfur	.41 A	.46 A	19.34 B	21.44 B
Magnesium	.68 A	.61 A	18.82 B	17.37 B
Calcium	1.86 A	2.01 A	56.95 B	60.07 B
Sodium	.06 A	.07 A	.97 B	1.21 C
Iron	.02 A	.02 A	.71 B	.64 B
Aluminum	.02 A	.02 A	.61 C	.48 B
Manganese	.01 A	.02 A	.74 B	.91 C
Boron	<.01 A	<.01 A	.09 B	.10 B
Copper	<.01 A	<.01 A	.07 B	.07 B
Zinc	.02 A	.02 A	.96 C	.45 B

Table 6—Significant effects ($p \leq 0.05$) of different spoil materials on nutrient uptake (micrograms/pot) by aboveground plant tissue following 110 days of growth. Means in the same row followed by different letters differ significantly

Nutrients/ elements	Perlite	Pumice	Perlite mill waste
Nitrogen	71.6 A	106.1 B	98.7 B
Phosphorus	11.6 A	20.1 B	19.7 B
Potassium	97.0 A	128.7 B	137.0 B
Sulfur	9.0 A	13.6 B	14.6 B
Sodium	1.04 B	.56 A	.44 A
Iron	.29 A	.47 B	.48 B
Manganese	.14 A	.57 B	.80 C
Boron	.05 A	.07 C	.06 B
Copper	.03 A	.05 B	.05 B

Figure 3—Significant effects ($p \leq 0.05$) of three spoil materials and three fertilizer rates on aboveground biomass, belowground biomass, and culm production. Differences between means are indicated by upper-case letters for spoil materials and by lower-case letters for fertilizer rates. Comparison of spoil materials is within fertilizer groups while fertilizer rate comparison is associated with identical spoil materials.

several light applications of fertilizer applied at about 2-year intervals may be more beneficial than a single larger application at the time of seeding (Tisdale and Nelson 1975).

Application of a surface straw mulch under nonstressful greenhouse conditions inhibited plant growth, possibly because of the negative effects of surface heat trapping or by creating an imbalance of the C:N ratio. Under stressful field conditions, however, we believe that mulching should have an overall beneficial effect on plant establishment and growth by reducing evaporation and by preventing soil erosion and seed displacement. Actually incorporating organic matter into the substrate, particularly with the addition of N, should facilitate microbial activity, induce development of a relatively complete soil biota, and result in higher rates of substrate decomposition and mineralization (Woods and Schuman 1986). Crimping straw or meadow hay into the soil surface can provide similar benefits attributed to both surface mulching and mulch incorporation.

The native rhizomatous grass (thickspike wheatgrass) and the introduced tussock hybrid (Hycrest wheatgrass) performed equally well in the greenhouse trials and appear well suited for revegetating the fertilized and mulched substrate from all three spoil materials. As a general practice, species for reclamation should be selected from native species growing on or near the area, or from introduced species on the basis of their ability to perform well under the climatic and edaphic conditions on the site. The planting of native or adapted introduced legumes could have the added benefit of not only providing N for their own needs but may provide some excess for other plants as well.

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Thickspike wheatgrass and Hycrest wheatgrass were grown in perlite ore, pumice ore, and perlite mill waste from a mine in southeastern Idaho. Results show that fertilization is necessary for grass establishment and that increasing fertilizer significantly ($p \leq 0.05$) increases aboveground biomass (up to 45-fold), belowground biomass (up to twentyfold), number of culms (ninefold), and average leaf length (up to 80 percent) over no fertilizer. Mulch equal to 2,200 kg/ha (2,000 lb/acre) significantly reduced all plant growth parameters.

KEYWORDS: *Agropyron dasystachyum*, *Agropyron cristatum* x *Agropyron desertorum*, perlite, pumice, revegetation

INTERMOUNTAIN RESEARCH STATION

The Intermountain Research Station provides scientific knowledge and technology to improve management, protection, and use of the forests and rangelands of the Intermountain West. Research is designed to meet the needs of National Forest managers, Federal and State agencies, industry, academic institutions, public and private organizations, and individuals. Results of research are made available through publications, symposia, workshops, training sessions, and personal contacts.

The Intermountain Research Station territory includes Montana, Idaho, Utah, Nevada, and western Wyoming. Eighty-five percent of the lands in the Station area, about 231 million acres, are classified as forest or rangeland. They include grasslands, deserts, shrublands, alpine areas, and forests. They provide fiber for forest industries, minerals and fossil fuels for energy and industrial development, water for domestic and industrial consumption, forage for livestock and wildlife, and recreation opportunities for millions of visitors.

Several Station units conduct research in additional western States, or have missions that are national or international in scope.

Station laboratories are located in:

Boise, Idaho

Bozeman, Montana (in cooperation with Montana State University)

Logan, Utah (in cooperation with Utah State University)

Missoula, Montana (in cooperation with the University of Montana)

Moscow, Idaho (in cooperation with the University of Idaho)

Ogden, Utah

Provo, Utah (in cooperation with Brigham Young University)

Reno, Nevada (in cooperation with the University of Nevada)